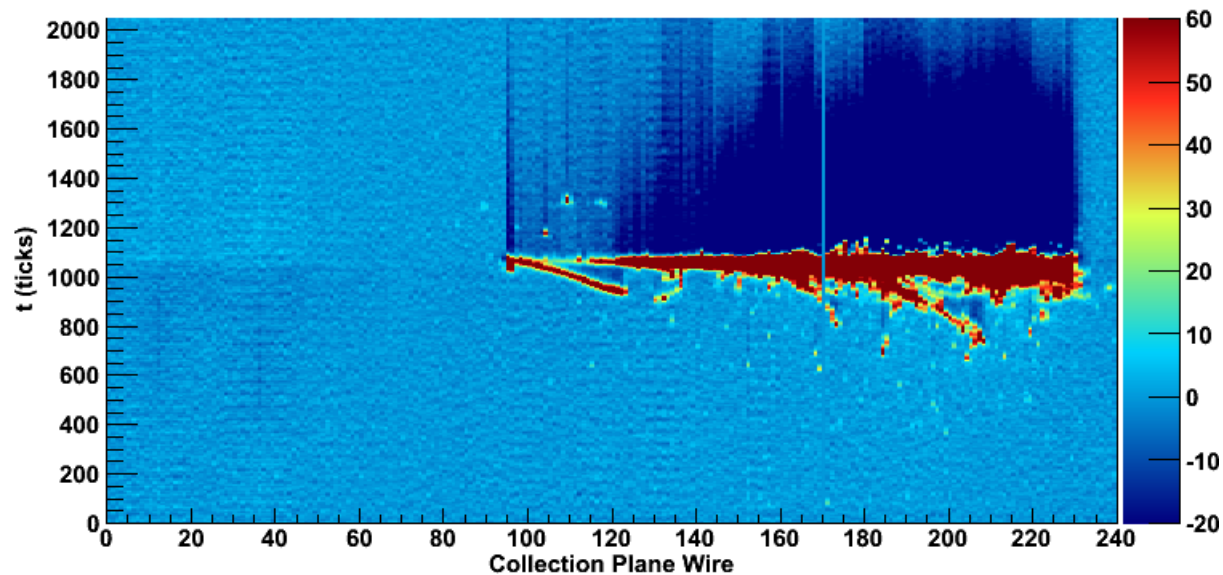
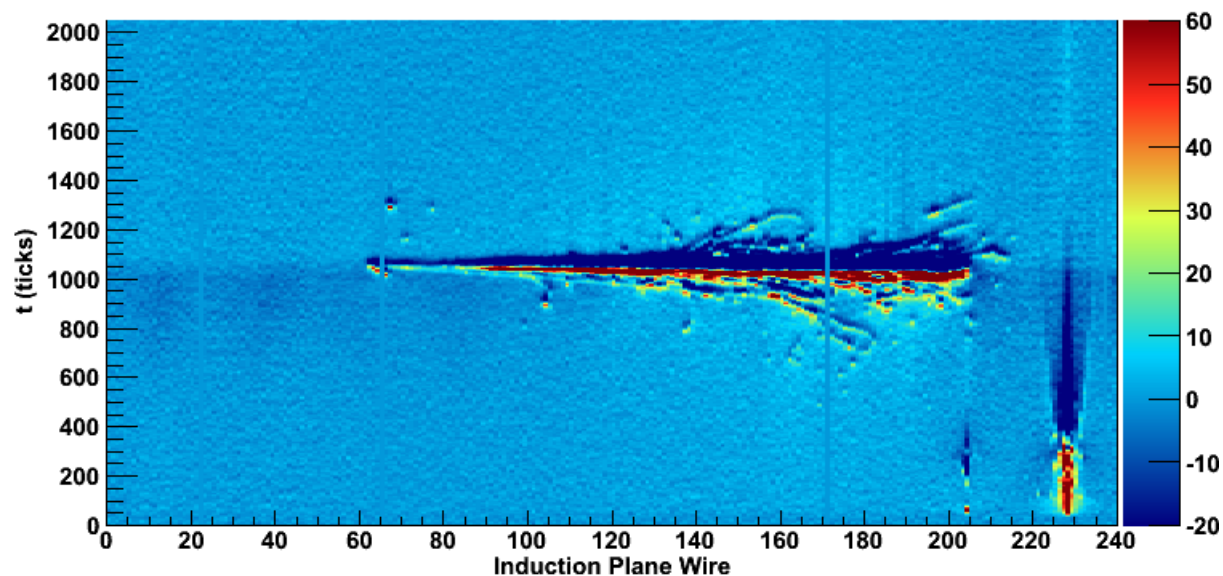


Physics R&D for LAr20 for LBNE

ArgoNeuT electron neutrino candidate



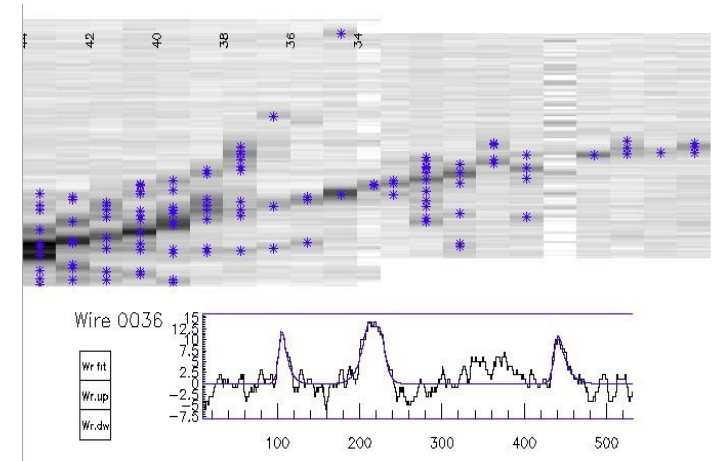
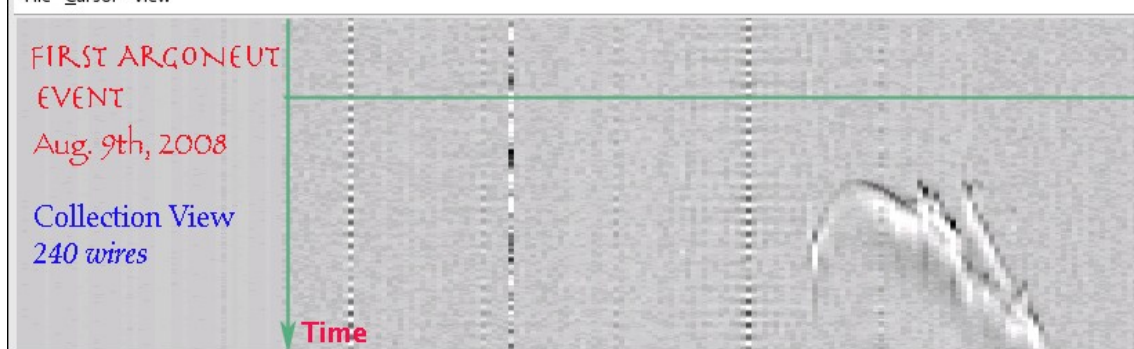
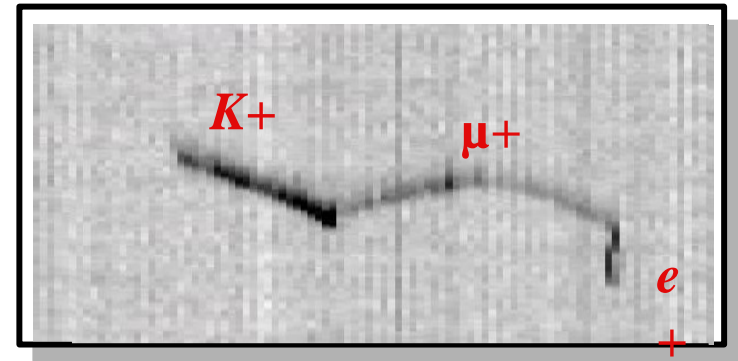
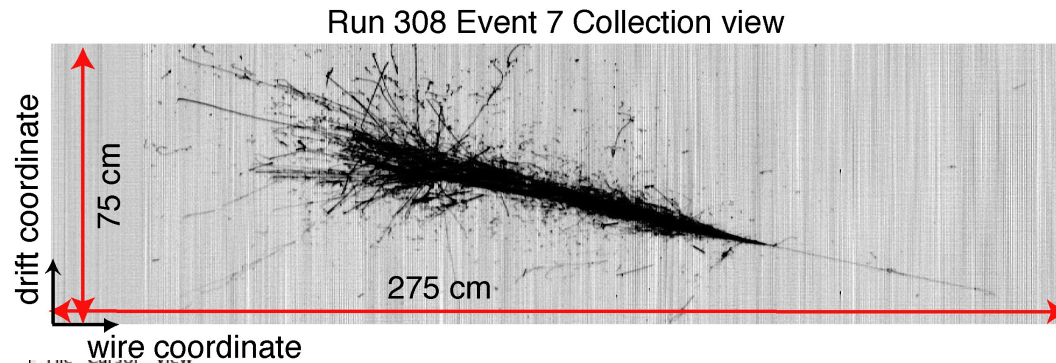
Physics R&D in the Integrated plan:

Physics R&D: Monte Carlo studies, physics measurements, and development of Analysis tools necessary to assess experimental sensitivities and do LBNE physics analysis.

- Collect and analyze neutrino interaction and calibration data on Argon
 - Measure neutrino interactions and cross sections to estimate sensitivities to neutrino oscillation physics and set design parameters for LBNE (wire spacing, number of wire planes...)
 - Study kaon interactions and cosmic backgrounds for proton decay studies
 - Study energy resolutions in a TPC in a test beam
 - Test cosmic ray background rejection while running on the surface
 - Develop data compression schemes for continuous data taking
 - Determine sensitivity to Supernova relic and burst neutrinos and develop Supernova triggering capabilities
- Develop Analysis tools (see Brian's talk for details)
 - Develop detailed MC simulation
 - Develop fully automated reconstruction

Physics Accomplishments from existing LarTPC activities

- Lots of simulation work from many groups worldwide
- Analysis of 50 liter data and ICARUS T300 surface test



Future Physics R&D that gets us to LAr20

- ArgoNeuT
- Calibration TPC test
- MicroBooNE experiment

(Also anticipate results from ICARUS and 5m drift tests in Europe)

Sensitivity to electron neutrino appearance searches

Work done so far:

- Electron neutrino efficiency: ~80-90%
- Neutral pion contamination: 0.2%-0.5%
- Muon momentum resolution via MS: ~12% (from MC studies and using ICARUS cosmic ray events collected in Pavia run: hep-ex/0606006v1)
- Electromagnetic shower resolution: 16% (hep-ex/0812.2373v1)

Translates to detector sensitivity x6 that of WC detectors

Existing work includes:

ICARUS MC and T300 data studies

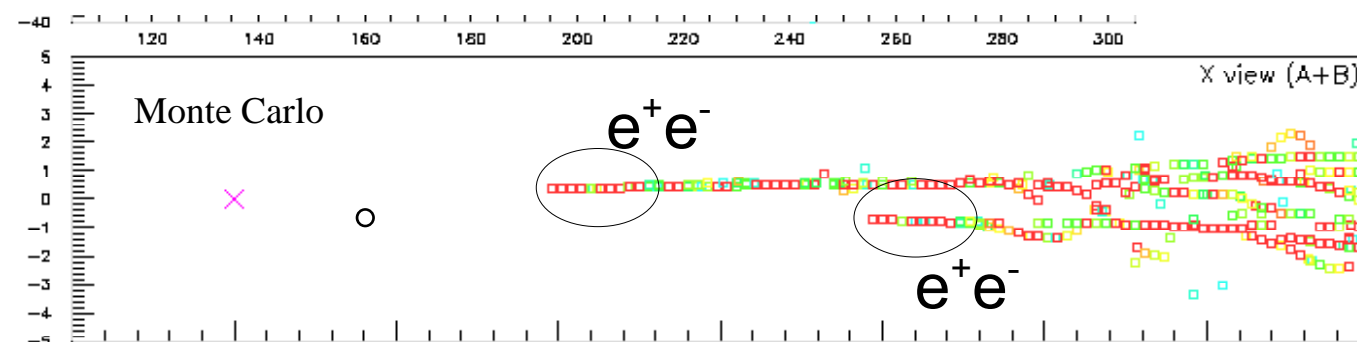
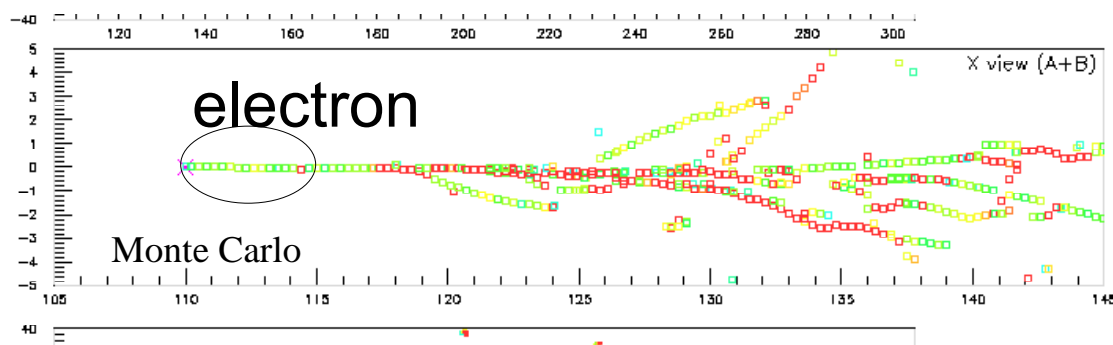
MicroBooNE Monte Carlo studies

Monte Carlo studies from T2K 2km effort (A. Rubbia)

Hand-scanning study from Tufts group

LArTPCs image events and collect charge
 Separates electrons from backgrounds with
 → gammas
 do e/gamma separation via dE/dx

look in first
 couple cm of
 track before
 shower begins



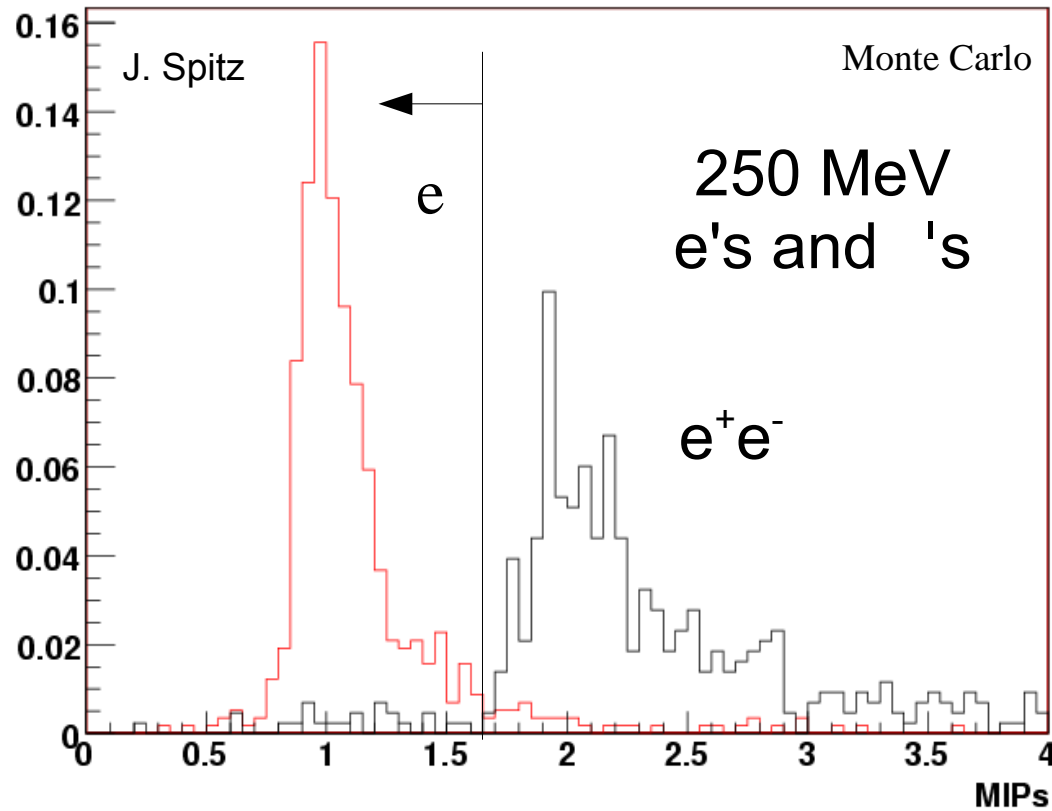
Where electrons
 deposit

1 MIP = green
 (MIP = minimum ionizing
 particle)

e^+e^-
 deposit
 2 MIPs = red

GEANT4 Monte Carlo Simulation

Energy loss in the first 24mm of track: 250 MeV electrons vs. 250 MeV gammas



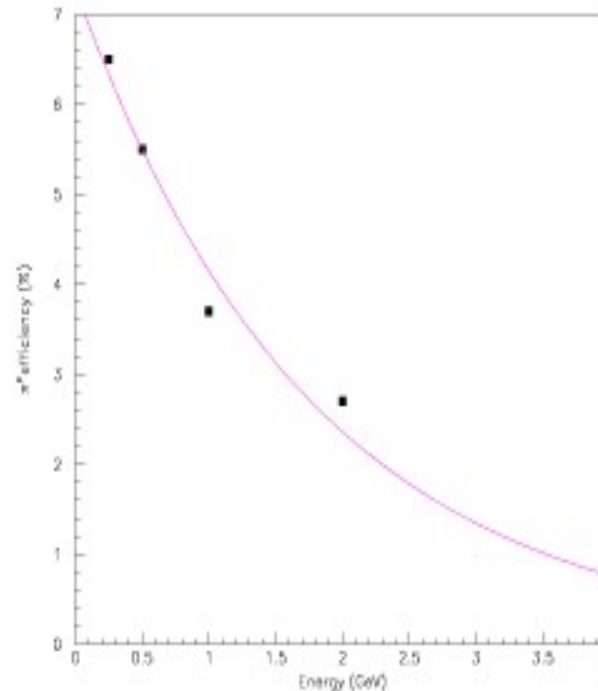
MIP deposition in first
2.4 cm of track

For electron
efficiency of
80%
contamination is
<5%

Similar studies
report 90% electron
efficiency for 6.5%
contamination

- T2K 2km studies from A. Rubbia's group:
- e/ π^0 separation
 - dE/dx in first 2.4 cm studied for 1000 e and π^0 events (simulation with noise): 0.25, 0.5, and 2 GeV

surviving pion fraction



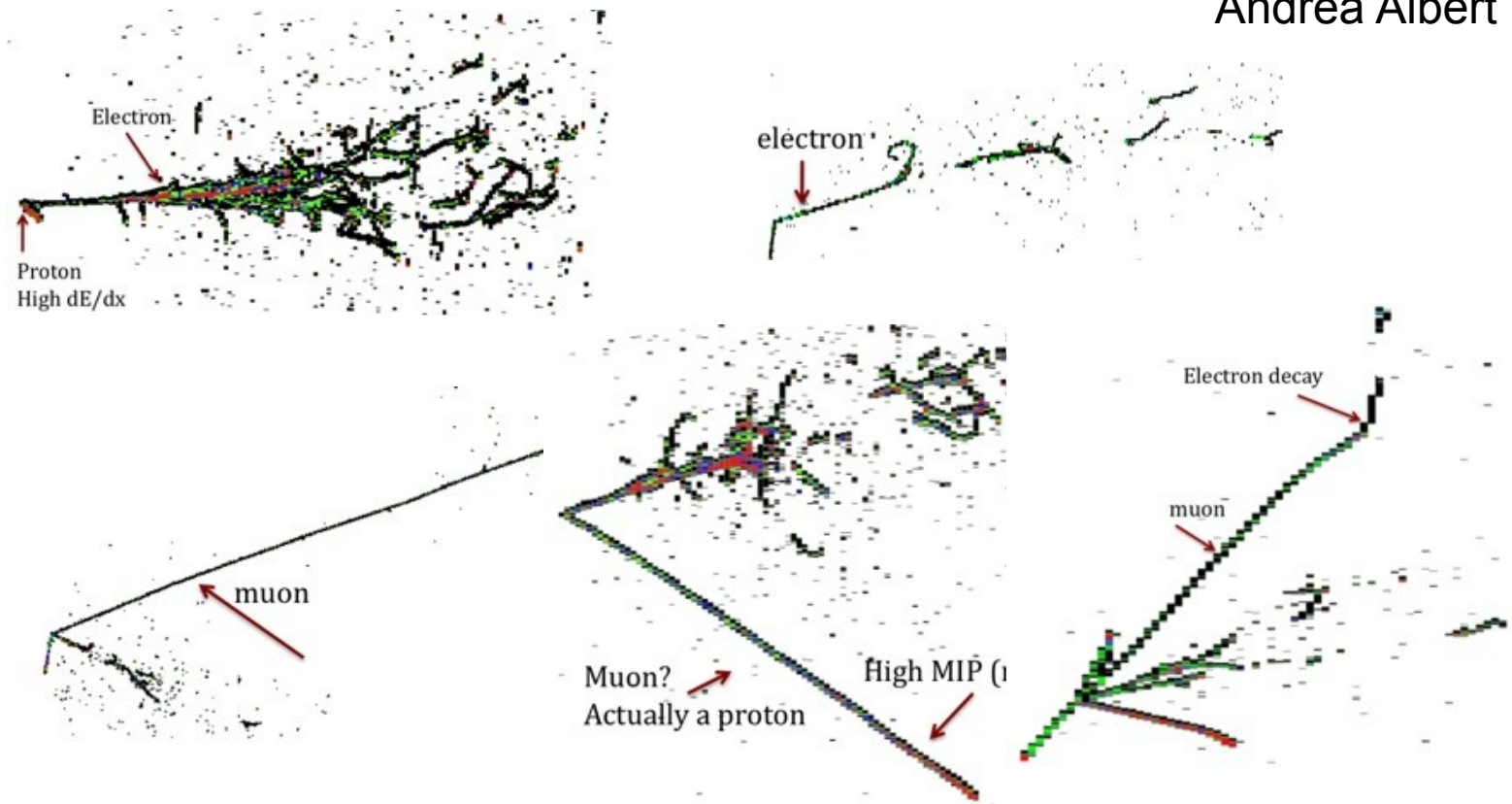
Rejection improves as E increases (as Compton Scattering process decreases)

Figure 33: Survival π^0 efficiencies as a function of the incoming energy. The points are simulations and the curve is the result of an exponential fit.

fold in vertex separation from hand scan: overall 0.2% inefficiency

Hand scanning study to determine efficiencies:

Andrea Albert



Both topology and dE/dx used to identify events
Assumes off-axis NuMI beam below 3.5 GeV at 800 km from FNAL

5mm pitch

train05_1.eye

Num: CCe 111 CCmu 379 CCtau 0 NC 1509

Number of events 93

*** Your selection ***

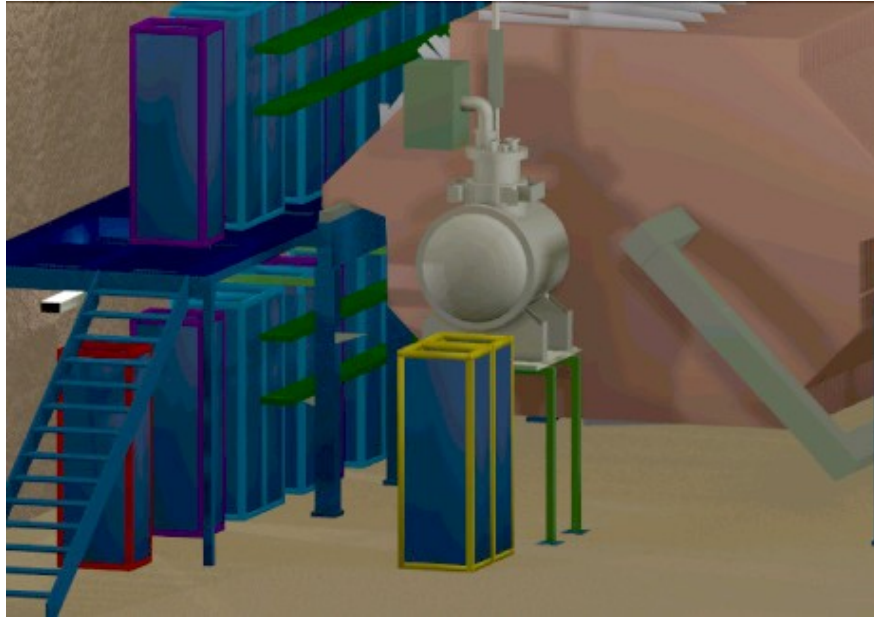
	CCe	CCmu	NC
true CCe	64	0	3
true CCmu	1	3	0
true NC	7	2	13

→ CCe Efficiency 95.5% NC rejection 99.54% CCmu rejection 99.74%

Still to do:

Near term studies to be done (6-9 months)

- Repeat hand scanning studies with latest MC simulation
- Use MC to address a few key near-term questions for LBNE
 - eg: What is the fiducial to active ratio for LBNE

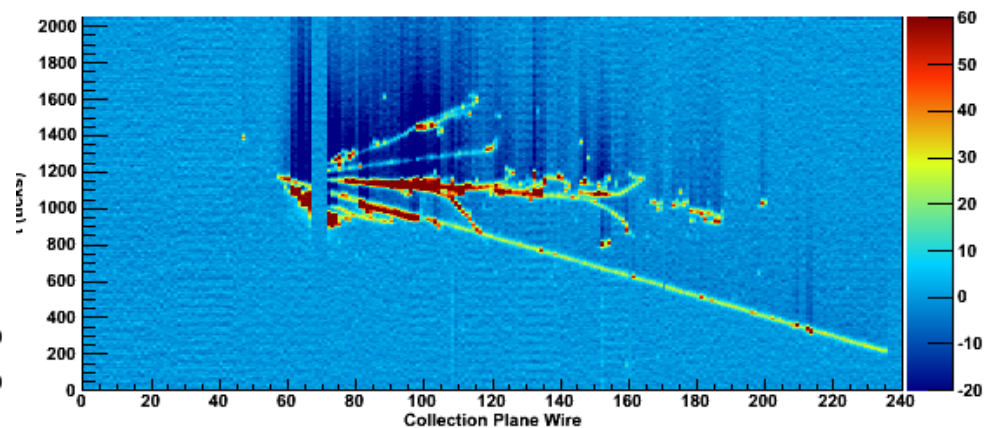
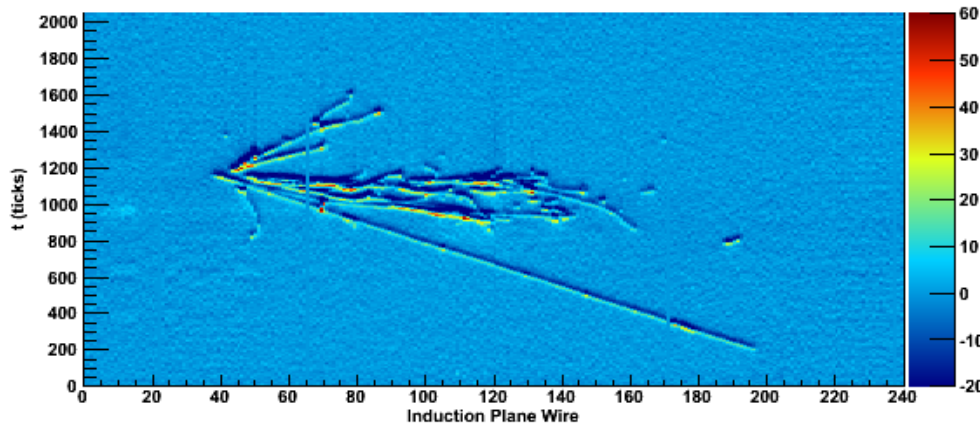


ArgoNeuT will collect ~15k events in first data run:

- Develop analysis tools with neutrino data
- Measure CCQE cross section
- Measure coherent vs resonant pion production
- Measure electron neutrino intrinsic events

Ph.D theses

0.3 ton TPC using MINOS to catch muons



Data run began mid-September – expect ~20k neutrino and anti-neutrino events by March

MicroBooNE: Large data set of neutrino interactions

J. Spitz	Nuance channel	Reaction	#interactions/6E20 POT 70 ton FV	% of total ν_μ
CCQE	1 (CC)	$\nu_\mu n \rightarrow \mu^- p$	52524	45.0
NCelastic	2 (NC)	$\nu_\mu N \rightarrow \nu_\mu N$	16945	14.5
Single pion resonant	3 (CC)	$\nu_\mu p \rightarrow \mu^- p \pi^+$	16124	13.8
	4 (CC)	$\nu_\mu n \rightarrow \mu^- p \pi^0$	6106	5.2
	5 (CC)	$\nu_\mu n \rightarrow \mu^- n \pi^+$	5833	5.0
	6 (NC)	$\nu_\mu p \rightarrow \nu_\mu p \pi^0$	2878	2.5
	7 (NC)	$\nu_\mu p \rightarrow \nu_\mu n \pi^+$	1819	1.6
	8 (NC)	$\nu_\mu n \rightarrow \nu_\mu n \pi^0$	3572	3.1
	9 (NC)	$\nu_\mu n \rightarrow \nu_\mu p \pi^-$	2368	2.0
DIS	91 (CC)	$\nu_\mu N \rightarrow \mu^- X$	1123	1.0
	92 (NC)	$\nu_\mu N \rightarrow \nu_\mu X$	410	0.4
Coherent/diffractive	96 (NC)	$\nu_\mu A \rightarrow \nu_\mu A \pi^0$	1479	1.3
	97 (CC)	$\nu_\mu A \rightarrow \mu^- A \pi^+$	2293	2.0
Subtotal			113474	97.3

	Nuance channel	Reaction	#interactions/6E20 POT 70 ton FV	% of total ν_e
CCQE	1 (CC)	$\nu_e n \rightarrow e^- p$	285	37.2
NCelastic	2 (NC)	$\nu_e N \rightarrow \nu_e N$	89	11.7
Single pion resonant	3 (CC)	$\nu_e p \rightarrow e^- p \pi^+$	110	14.4
	4 (CC)	$\nu_e n \rightarrow e^- p \pi^0$	48	6.3
	5 (CC)	$\nu_e n \rightarrow e^- n \pi^+$	53	6.9
	6 (NC)	$\nu_e p \rightarrow \nu_e p \pi^0$	19	2.5
	7 (NC)	$\nu_e p \rightarrow \nu_e n \pi^+$	13	1.7
	8 (NC)	$\nu_e n \rightarrow \nu_e n \pi^0$	24	3.1
	9 (NC)	$\nu_e n \rightarrow \nu_e p \pi^-$	17	2.2
DIS	91 (CC)	$\nu_e N \rightarrow e^- X$	26	3.4
	92 (NC)	$\nu_e N \rightarrow \nu_e X$	9	1.1
Coherent/diffractive	96 (NC)	$\nu_e A \rightarrow \nu_e A \pi^0$	9	1.1
	97 (CC)	$\nu_e A \rightarrow e^- A \pi^+$	17	2.2
Subtotal			719	93.9

Suite of low energy cross section measurements

- ▣ 15k contained CCQE events
- ▣ Coherent vs. resonant pion production
- ▣ K production: cross sections and proton decay studies
- ▣ Electron neutrino cross sections

Development goals

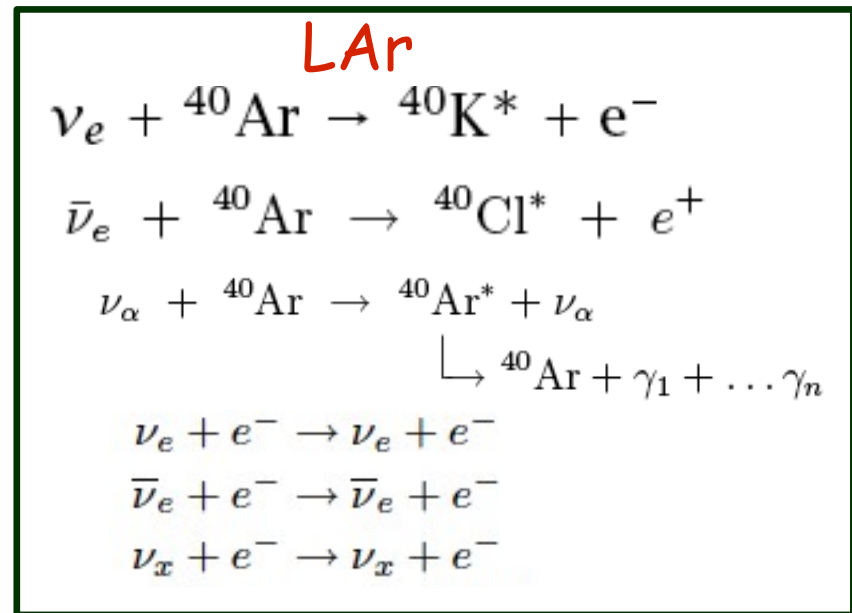
- Study ability to reject backgrounds for surface operations
- Study light collection both for triggering and for physics measurements

Sensitivity to supernova relic and burst studies

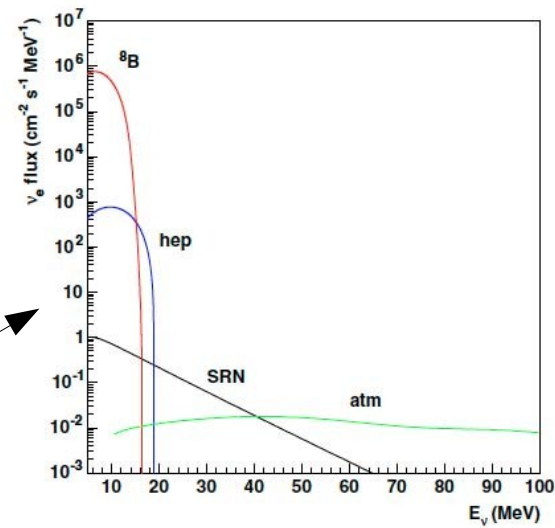
100 kt of LAr, SN @ 10 kpc

Interaction	Rates ($\times 10^4$)
ν_e CC (^{40}Ar , $^{40}\text{K}^*$)	2.5
ν_x NC ($^{40}\text{Ar}^*$)	3.0
ν_x ES	0.1
anti- ν_e CC (^{40}Ar , $^{40}\text{Cl}^*$)	0.054

Sizable rates for SN bursts
Backgrounds for SN relic –
solar neutrinos at low
energies and atmospheric at
higher energies
Sensitivity, eg: 1.7 ± 1.6 events
in 3kton detector running for 5
years...(hep-ph/0408031)

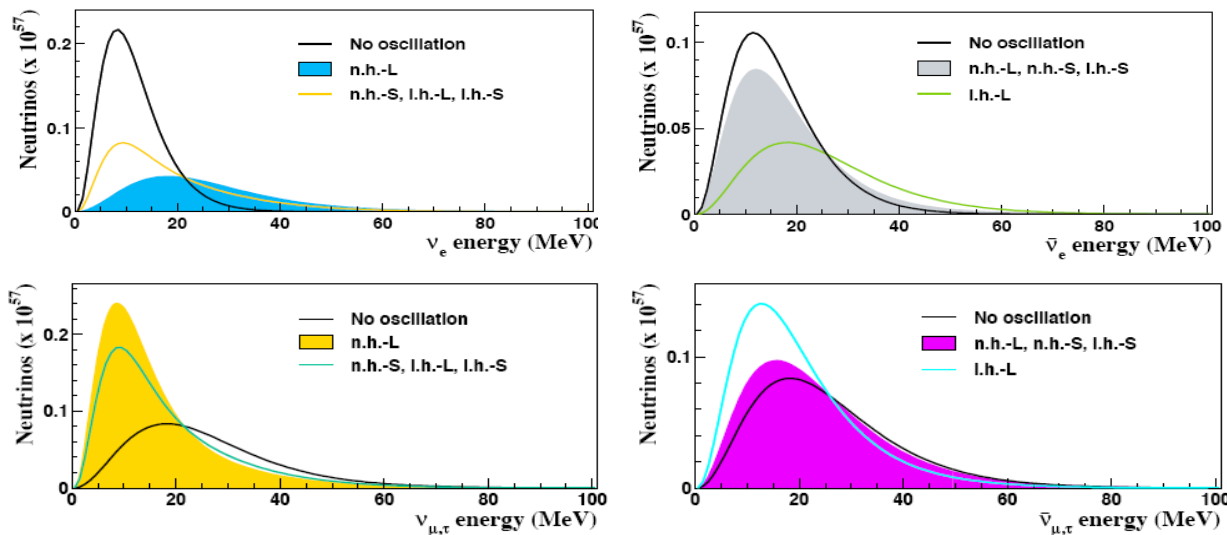


A. Bueno NP2008, via K.Scholberg



MicroBooNE secondary physics goal: Ability to detect Supernova

- Just a handful of events from a SN can teach us a lot (tens of events from Supernova 1987A generated many papers). MicroBooNE would collect 25-30 charged current events from a galactic SN and an equal number from neutral current interactions should these be reconstructable
- Events on Argon are complementary to events in WC detectors
 - Dominant interaction in WC is inverse beta-decay on anti-electron neutrinos
 - Dominant interaction in Argon is charged current interaction of electron neutrinos



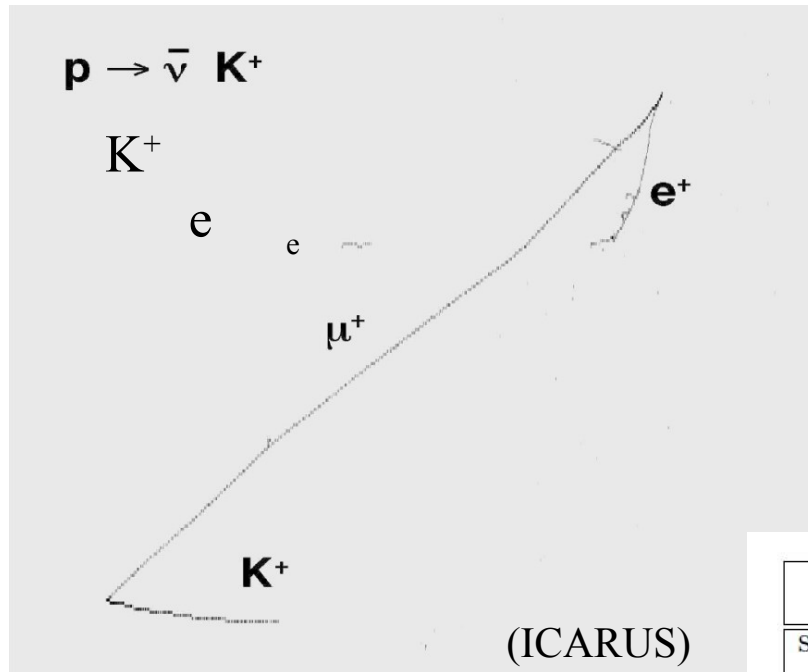
Modest expansion to
MicroBooNE electronics
design required to be SN
live

SN triggering studies:
Will have capability on
MicroBooNE to read out
continuously to be able
to do studies of
continuously live
running

Proton decay physics R&D

Next generation LArTPCs for LBNE can extend sensitivity to proton decay in neutrino + kaon mode. How well can this be done?

Already substantial MC work to estimate PD sensitivity vs depth (eg: hep-ph/0701101)



Simulated K^+ event in LAr

~300 kaons expected from BNB and NuMI

Understand signal and backgrounds
(like $K2K \rightarrow$ SuperK: hep-ex/0801.0182)
using beam neutrino interactions

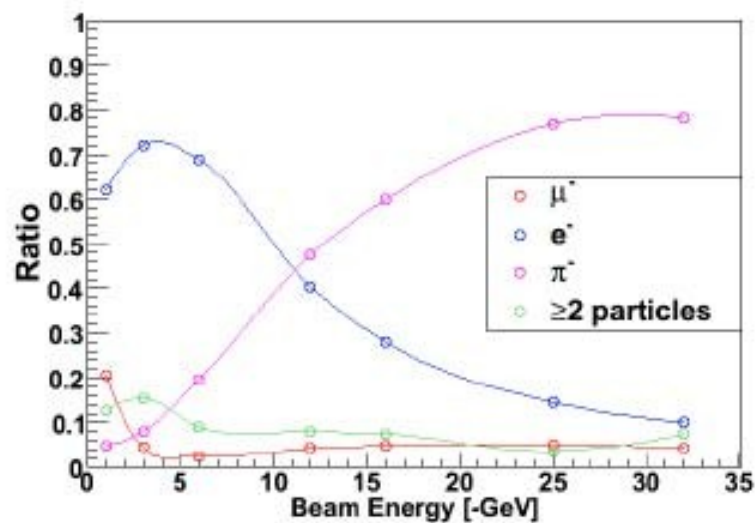
dE/dx measurements study kaon “signal”
ID and background rejection

J. Spitz	Nuance channel	Reaction	interactions/6E20 POT 70 ton(90 ton) FV	xsec uncertainty
Single kaon resonant	53-55 (CC)	$\nu_\mu N \rightarrow \mu^- \Sigma K$	5(7)	~40%
	56-59 (NC)	$\nu_\mu N \rightarrow \nu_\mu \Sigma K$	3(4)	~40%
	73 (CC)	$\nu_\mu n \rightarrow \mu^- K^+ \Lambda$	47(61)	~40%
	74 (NC)	$\nu_\mu p \rightarrow \nu_\mu K^+ \Lambda$	8(10)	~40%
	75 (NC)	$\nu_\mu n \rightarrow \nu_\mu K^0 \Lambda$	11(14)	~40%
DIS	91 (CC) post-FSI	$\nu_\mu N \rightarrow \mu^- X K$	50(64)	~25%
	92 (NC) post-FSI	$\nu_\mu N \rightarrow \nu_\mu X K$	12(16)	~25%
Subtotal			131(169)	

TPC Calibration test: Put TPC in Fermilab MTest beam
Possibly re-use ArgoNeuT cryostat

Measured rates for 1E11 at MW 1SEM

Beam Energy (GeV)	Rate at Entrance to Facility (per spill)	Rate at Exit of Facility (per spill)	%Pions, Muons**	% Electrons**
16	132,000	95,000	87%	13%
8	89,000	65,000	55%	45%
4	56,000	31,000	31%	67%
2	68,000	28,000	<30%	>70%
1	69,000	21,000	<30%	>70%



Scientific resources:
Collaborations are growing – still needs to grow more...

ArgoNeuT collaboration

F. Cavanna

University of L'Aquila

B. Baller, C. James, G. Rameika, B. Rebel

Fermi National Accelerator Laboratory

M. Antonello, R. Dimaggio, O. Palamara

Gran Sasso National Laboratory

C. Bromberg, D. Edmunds, P. Laurens, B. Page

Michigan State University

S. Kopp, K. Lang

The University of Texas at Austin

C. Anderson, B. Fleming, S. Linden, M. Soderberg*, J.
Spitz, T. Wongjirad, K. Partyka, D. Chari

Yale University

MicroBooNE Collaboration:

- *Brookhaven Lab*: H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowieczi, J. Mead, V. Radeka, S. Rescia, J. Sondericker, C. Thorn, B. Yu
- *Columbia University*: L. Camilleri, C. Mariani, M. Shaevitz, B. Willis**
- *FermiLab*: B. Baller, C. James, S. Pordes, G. Rameika, B. Rebel, D. Schmitz, J. Wu
- *Kansas State University*: T. Bolton, G. Horton-Smith, D. McKee
- *Los Alamos Lab*: G. Garvey, J. Gonzales, B. Louis, C. Mauger, G. Mills, Z. Pavlovic, R. Van de Water, H. White, S. Zeller
- *Massachusetts Institute of Technology*: W. Barletta, L. Bugel, J. Conrad, C. Ignarra, B. Jones, G. Karagiorgi, T. Katori, H. Tanaka
- *Michigan State University*: C. Bromberg, D. Edmunds
- *Princeton University*: K. McDonald, C. Lu, Q. He
- *St. Marys*: P. Nienaber
- *University of California, Los Angeles*: H. Wang
- *University of Cincinnati*: R. Johnson, A. Wickremasinghe
- *University of Texas at Austin*: S. Kopp, K. Lang
- *Yale University*: C. Anderson, B. T. Fleming*, S. Linden, M. Soderberg, J. Spitz

*=Spokesperson, **=Deputy Spokesperson

58 scientists from
13 institutions
More than doubled in a year

Summary

- Substantial Monte Carlo work already done demonstrating the power of the technique for neutrino physics and nucleon decay
- Near term Monte Carlo work will help to set LBNE design parameters
- Data from ArgoNeuT and MicroBooNE will complete Physics R&D program for LBNE
- With what is learned from this program through MicroBooNE, we can proceed to LAr20.

